DOCUMENT RESUME

ED 050 994 SE 011 365

AUTHOR	Koran, John J., Jr.
TITLE	Teaching High School Science.
INSTITUTION	National Science Teachers Association, Washington, D.C.
PUB DATE	70
NOTE	36p.
AVAILABLE FROM	Publications-Sales Section, National Education Association, 1201 Sixteenth Street, N.W., Washington, D.C. 20036 ($0.50)
EDRS PRICE	EDRS Price MF-$0.65 HC Not Available from EDRS.
DESCRIPTORS	Educational Objectives, *Instruction, *Research Reviews (Publications), Resource Materials, Science Education, *Secondary School Science, *Teacher Behavior, *Teaching Methods

ABSTRACT

This pamphlet, replacing an earlier edition with the same title, reviews the research related to science instruction in high schools with reference to its implications for teaching. Recommendations for particular teaching methods are made when the evidence is strong, and, where it is weak, implications of the trends discerned are stated, and teachers are advised that particular techniques may be advantageous. Topics reviewed include the use of instructional objectives; the nature and utility of advanced organizers and learning set; the nature of teacher behavior in the new science programs; the use and effectiveness of a variety of instructional methods and materials; and methods of developing scientific skills and inquiry techniques. Comparative studies of alternate courses in relation to creativity; affective, conceptual, factual, scientific understanding; and critical thinking outcomes are reviewed separately. Fifty-six citations are made in the bibliography which includes entries published from 1951 to 1969. Most entries are from 1963 to 1969. (AL)

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Teaching High School Science

John J. Koran, Jr.

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ASSOCIATION OF CLASSROOM TEACHERS
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Teaching High School Science

CONTENTS

EXPLANATION 2
INTRODUCTION 3
GOALS OF SCIENCE INSTRUCTION 4
INSTRUCTIONAL OBJECTIVES IN SCIENCE 6
The Nature of Instructional Objectives 8
Functions of Instructional Objectives 8
Research Relating to Instructional Objectives 8
ADVANCE ORGANIZERS AND LEARNING SET 9
TEACHER BEHAVIOR IN NEW SCIENCE PROGRAMS 10
OUTCOMES OF INSTRUCTION 13
Factual and Conceptual Outcomes 13
Understanding of Science and Critical Thinking Outcomes . 13
Affective Outcomes 16
Creativity Outcomes 18
INSTRUCTIONAL METHODS AND MATERIALS 19
Flexible Scheduling and Team Teaching 20
Film Instruction 21
Visual Aids 22
Programed Instruction and Computer-Assisted Instruction .. 22
Audiotutorial or Multimedia Systems 23
Organization of Content 24
Concept Formation 25
SCIENTIFIC SKILL DEVELOPMENT 27
THE EVALUATION OF LEARNING 29
SELECTED REFERENCES 29

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EXPLANATION

This booklet, written by John J. Koran, Jr., assistant professor of curriculum and instruction and science education, The University of Texas, Austin, completely replaces the version by J. Darrell Barnard, last issued in April 1968. Professors Paul DeHart Hurd of Stanford University and Fletcher G. Watson of Harvard University provided critiques of Professor Koran's preliminary materials and made helpful suggestions. Suggestions were made also by staff members of the National Science Teachers Association, the Association of Classroom Teachers, and the NEA Publications Division. Although these suggestions were carefully considered, the author is responsible for the text in its present form.

Copy editing and editorial production were handled by Mrs. Kirsten Gardner of the Publications Division.

TEACHING HIGH SCHOOL SCIENCE

INTRODUCTION

Science instruction and research in science education have undergone tremendous change since 1957, when the Russians launched Sputnik I. The challenge which this achievement represented to American education was met by the development of new curriculums in the schools. In the field of high school science a number of national curriculum groups were established to develop a wide range of contemporary science curriculums. Project Physics, Biological Science Curriculum Study (BSCS), Chemical Education Materials (CHEM Study), and Earth Science Curriculum Project (ESCP) are a few such new science curriculums. In addition, research in science education proliferated.

Early studies during this period attempted to compare new curriculums with those already in use, specific materials with alternatives, and alternative teaching strategies. Perhaps more significantly, these studies attempted to identify curriculum-related behaviors of science teachers and to correlate these with changes in the behavior of students. During this period there has also been an attempt to tie a plethora of teacher, student, and curriculum variables together through correlational studies. The results have been a multitude of studies stemming from an atheoretical base and contradictory or, at best, inconclusive findings. A major problem is that it is difficult, if not impossible, to generalize from studies which fail to describe clearly what is meant by terms such as *inductive teaching, BSCS teaching,* or the *historical method.* Without the universal adoption and use of operational definitions in research it is difficult to build theories of instruction or learning in science. Consequently, this booklet will describe the territory of research relevant to science instruction, but draw few conclusions. It is necessary to look at curriculum innovations, materials, and techniques with some scepticism. The generalizations which follow should be tested in individual classrooms, under conditions and circumstances which can be clearly identified and described. In short, it is hoped that this booklet will be fruitful in suggesting useful types of materials and procedures to test in the classroom. The following discussions are not necessarily intended as solutions.

In the final analysis the science teacher is the researcher who counts. He is working directly with students and curriculums, and probably is in the best position to test the effects of teaching strategies, media, and the like on student learning. Moreover, of all subject area teachers the teacher of science seems particularly suited to engage in hypothesis making and testing and evaluation of data (11).

The development and testing of curriculum materials is a difficult area to study and one in which outcomes are tempered by the inability of the researcher to control variables, such as teacher behavior and random assignment, and at the same time to measure relevant student learning. The teacher is in a position to do this on a limited scale and to provide systematic feedback to curriculum developers while they are developing or revising materials. For instance, we need to know the effects of subsets of materials with different kinds of students. We also need to know the effects of certain combinations and sequences of instruction and materials. By subdividing his classes and testing limited hypotheses the science teacher can be a vital aide and experimenter in this quest for knowledge. It is no longer practical or wise to justify the production or existence of instructional materials on the basis of teacher and student happiness.

Each day teachers decide to teach in certain ways. They vary their use of materials according to some intuitive notions about what will be successful and effective. It is necessary to systematize this to the point that we can test in the classroom sequences of content, combinations of content and media, and—of extreme importance—teacher behavior in connection with various materials. With the advent of improved research in science education and increased teacher participation in research on teaching and learning science, future editions of What Research Says to the Teacher of Science should become much more definitive.

GOALS OF SCIENCE INSTRUCTION

In the past, science instruction consisted of communicating a large body of facts and conclusions to students and providing the opportunity for verification of them in the laboratory. Examination of textbooks and laboratory materials in use prior to 1957 in biology, chemistry, and physics indicated that much of the factual

material was outdated and that the laboratory materials and procedures did not reflect the nature of scientific exploration. As knowledge continued to multiply, it became apparent that science instruction should emphasize unifying themes in each of the disciplines and that laboratory experiences should prepare students to acquire and process knowledge about their surroundings. Students must be prepared to assume a role in an intellectual and cultural environment characterized by rapid change. Educators concluded that if science instruction were modified to correspond more closely with the structure and nature of science, students would gain the skills a rapidly changing society needed.

Briefly, the structure of each of the science disciplines—biology, chemistry, physics, and geology—is made up of facts and concepts or generalizations which can be organized into conceptual schemes or themes. The procedure through which basic concepts and conceptual schemes are acquired and understood is frequently referred to as *inquiry,* or the active engagement in certain scientific processes. Although the discipline may vary and consequently the basic concepts and some of the conceptual schemes as well, the scientific processes or inquiry activities through which knowledge in science is acquired remain relatively stable. Laboratory experience and the skills acquired through this experience remain the underpinning of each of the science disciplines and a certain orientation students should develop to their environment. A major goal of contemporary secondary school science instruction is, then, to arrange conditions in the classroom and the laboratory so that students may acquire and apply both the concepts and the methods of science. This approach appears to provide for greater adaptability to a changing world than did the earlier programs emphasizing memorization of facts and procedures and the use of the laboratory to confirm or illustrate them.

Accordingly, the greatest single change in high school science may well have been from laboratory experiences which emphasized confirmation of given conclusions to more open-ended student exploration and explanation. Very few experiences of the future will call upon skills developed in the former type of laboratory. Laboratory experiences should include opportunities for students to interpret observations and data, to evaluate their procedures and the data derived from them, and to attempt to

derive meaning from these. One cannot fully understand the role of laboratory activities if experiences are limited to collecting, summarizing, and reporting data. Students must learn to move from data to making generalizations to testing these against theory.

To summarize, our present needs call for science instruction which gives students a conception of the structure of science and, through experience in the laboratory, a way to think, to look at the world, and hopefully to change with a changing world.

INSTRUCTIONAL OBJECTIVES IN SCIENCE

In the largest sense, the goal of science instruction is to produce scientifically literate persons. Such a person has been described in the following way:

- He has faith in the logical processes of science and uses its modes of inquiry, but at the same time recognizes both their limitations and the situations for which they are peculiarly appropriate.
- He enjoys science for the intellectual stimulus it provides, for the beauty of its explanations, the pleasure that comes from knowing, and the excitement stemming from discovery.
- He has more than a commonsensical understanding of the natural world.
- He appreciates the interaction of science and technology, recognizing that each reflects as well as stimulates the course of social and economic development, but he is aware that science and technology do not progress at equal rates.
- He is in intellectual possession of some of the major concepts, laws, and theories of several sciences.
- He understands that science is one but not the only way of viewing natural phenomena, and that even among the sciences there are rival points of view.
- He appreciates that knowledge is generated by people with a compelling desire to understand the natural world.
- He recognizes that knowledge in science grows, possibly without limit, and that the knowledge of one generation "en-

gulfs, upsets, and complements all knowledge of the natural world before."

- He appreciates the essential lag between frontier research and the popular understanding of new achievements and the importance of narrowing the gap. . . .
- He recognizes that the achievements of science depend as much on its inquiry process as on its conceptual patterns and theories.
- He understands the role of the scientific enterprise in society and appreciates the cultural conditions under which it thrives (37).

To these characteristics, we might add another important characteristic:

- He recognizes the universality of science; it has no national, cultural, or ethnic boundaries.

However valuable broadly stated goals as appear above are in providing a sound philosophical basis for science instruction, such goals don't provide any information about how the teacher should perform, what materials and procedures he should use, and what the student must do or say to indicate achievement of the goal. In order to act on a goal the goal must be made operational. If the goal is to recognize that the meaning of science depends as much on its inquiry process as on its conceptual patterns and theories, some simple and precise instructional objectives leading to this goal would have to be elaborated. For example:

1. The student will be able to define a theory.
2. The student will be able to describe a concept and discuss its relationship with other concepts.
3. The student will be able to formulate hypotheses about the causes of observed phenomena.

Once these objectives are identified, the teacher can select appropriate materials, procedures, strategies, and measures to determine when the student has achieved the outcomes thought to mark attainment of the goal.

The Nature of Instructional Objectives

An instructional objective should take into account (a) the nature of the performance desired; (b) the instructional conditions under which the performance will occur; and (c) the way the performance will be evaluated and the nature of a minimal satisfactory performance. These factors need not be written down unless the intent is to communicate them or replicate certain procedures to achieve the same objective. However, instructional objectives should be prominent concerns of the teacher as he chooses between alternate courses of action prior to and during instruction.

Functions of Instructional Objectives

Instructional objectives function to identify for both the teacher and the learner in science the expected outcomes of instruction. They provide a basis for the selection of content and the organization of materials and experiences by the teacher. They require that the teacher think of student learning and the goals and objectives of the discipline of science rather than of his own performance in the abstract. Instructional objectives provide a basis for assessing entering and exiting behaviors of students, for individualizing instruction by task, and for classifying both student and teacher behaviors in terms of higher and lower cognitive and affective types of behaviors (28). Finally, instructional objectives provide the basis for a systematic approach to instruction, rather than the haphazard and random approach sometimes characteristic of science instruction.

Instructional objectives do not provide a panacea for science instruction. There are many objections to the use of these objectives (3), and equally convincing arguments for their use (41). In the final analysis, the science teacher will have to weigh the evidence of research and test the use of objectives in the classroom before reaching a conclusion regarding how objectives will work for him.

Research Relating to Instructional Objectives

The teacher may well ask: "If I formulate instructional objectives and make them known, will my students achieve more in

science?" Preliminary evidence from various sources suggests that the answer is Yes. Two researchers found that a learner will function better if he is clear as to what he is to learn and how he is to learn it (33, 44). Similarly, a third observed that when outcomes of instruction or the achievement of specific objectives are emphasized, there is greater achievement (54). If the aforementioned studies can be generalized to science instruction, it might be concluded that when a teacher knows what he wants to accomplish in science and the performance outcomes are clearly apparent to his students, the students are likely to learn more than if the outcomes are vague to both of them. (This should not, however, be taken to mean that laboratory behavior should be so rigidly specified that inquiry is eliminated; rather, the acquisition of laboratory skills for open inquiry constitutes an objective in itself.)

ADVANCE ORGANIZERS AND LEARNING SET

In connection with specifying instructional objectives, two procedures are of interest. As a result of considerable research and theory development in cognitive psychology, a well-known researcher proposed a construct called an "advance organizer" (5, 6). He defines this as material, usually written, introduced at a high level of abstraction, generality, and inclusiveness, which he feels will facilitate meaningful verbal learning and retention. This material is introduced before instruction and is thought to provide a framework within which more detailed materials can be incorporated. This framework serves as an anchorage for completely new material which has not been incorporated into the thinking structure or for concepts which are related to previously incorporated conceptual knowledge. Science educators are interested in this construct because the science disciplines have definable structures which undoubtedly have a bearing on the way science knowledge is assimilated and used for thinking. To construct an advance organizer a teacher has to "clearly, precisely, and explicitly" identify the major generalities which are to serve as the framework for incorporating new knowledge. This framework might be provided in outline or prose form to students prior to instruction. The instruction then would be focused on developing

the particular information and concepts which the outline subsumed.

A learning set may be considered as a description, prior to instruction, of what will be taught, how, using what materials, and why. It also may include a statement of objectives. In a group of experiments on establishing set in BSCS biology, one researcher found that students achieve more and consider teachers more effective when they are advised prior to instruction what is to be taught and what their responses should be (48). In psychological literature, learning sets are considered to be the behaviors or content which must be known prior to acquiring new, related knowledge. Although learning sets rarely include as systematic and precise a written or oral set of generalizations as does the advance organizer, both approaches appear to be useful procedures. Even though the identification, elaboration, and explicit delineation of advance organizers are difficult if not impossible tasks for the practicing teacher, when advance organizers are available or can be developed, their use and the use of sets seems recommended.

TEACHER BEHAVIOR IN NEW SCIENCE PROGRAMS

The new curriculums—Project Physics, BSCS, CHEM Study, and ESCP—developed since 1957 are directed toward the achievement of specific goals of science instruction. (It should be mentioned that since the quality of the various programs varies, the success of each in achieving its goals likewise varies.) In all cases, in order to accomplish goals, curriculum developers have identified objectives for each of the curriculums. However, a problem which remains for each of the curriculums once objectives are specified is to develop a model of teacher behavior which will lead to achievement of these objectives by students. If the model is carefully derived from the philosophy, rationale, and objectives of a given curriculum, it should not only be possible to predict teacher behavior, but also to hypothesize related student achievement. A number of curriculum developers observe that there is a tremendous need for this kind of thought and elaboration since the evidence of research suggests that after more than

a decade of curriculum development and teacher education in science, "it appears that as many as two-thirds of the teachers using the textbooks of the new curricula are not teaching the courses in the mode envisioned by the authors" (20). If we can assume that the teaching mode envisioned by the authors would enhance student learning of science, this disclosure is certainly a sad commentary. Science teachers must adopt teaching styles which are consistent with the nature of science and designed to elicit the desired outcomes of science instruction. But, the question may be asked: What are these styles and how do they connect with student learning?

An early study attempted to derive those characteristics of instruction which appear to be prescribed by the BSCS philosophy and rationale. To accomplish this an initial list of classroom practices was submitted to BSCS judges, who thereupon identified characteristics which, in their opinion, contributed either positively or negatively toward BSCS objectives. The activities that were finally selected were organized into a student questionnaire. Recommended practices can be inferred from the following extracts from the questionnaire:

1. My teacher often asks us to explain the meaning of certain things in the text.
2. My teacher asks questions that cause us to think about things that we have learned in other chapters.
3. My teacher often asks questions that cause us to think about the evidence that is behind statements in the textbook.
4. We students are often allowed time in class to talk among ourselves about ideas in biology.
5. Classroom demonstrations are usually done by students rather than by the teacher.
6. If I don't agree with what my teacher says, he wants me to say so.
7. We often talk about the kind of evidence that is behind a scientist's conclusion.
8. When reading the textbook, we are always expected to look for the main problems and for the evidence that supports them.
9. Our teacher has tried to teach us how to ask questions of the text.

10. We sometimes read the original writings of the scientists.
11. We are seldom or never required to outline sections of the textbook.
12. Our tests include many questions based on things that we have learned in the laboratory.
13. Our tests often ask us to relate things that we have learned at different times.
14. Our tests often ask us to figure out answers to new problems.
15. Our tests often give us new data and ask us to draw conclusions from these data.
16. We spend some time before every laboratory in determining the purpose of the experiment.
17. We often use the laboratory to investigate a problem that comes up in class.
18. The laboratory usually comes before we talk about the specific topics in class.
19. The data that I collect are often different from data that are collected by other students.
20. During experiments we record our data at the time we make our observations.
21. We are sometimes asked to design our own experiments to answer a question that puzzles us.
22. The teacher answers most of our questions about the laboratory work by asking us questions.
23. We talk about what we have observed in the laboratory within a day or two after every session.
24. After every laboratory session, we compare the data we have collected with the data of other individuals or groups.
25. We are expected to go beyond the regular laboratory exercise and do some experimenting on our own.
26. We have a chance to analyze the conclusions that we have drawn in the laboratory (25).

A checklist similar to the one previously described but focusing on laboratory activities was also designed. This checklist emphasized such characteristic laboratory activities as (a) investigating class-derived problems; (b) utilizing the laboratory as a preparation for classroom learning; (c) identifying the variability of data;

(d) recording and interpreting; (e) using teacher probing questions and cues during laboratory; (f) using laboratory equipment and experience with graphs, charts, etc.; and (g) relating the laboratory experience to the nature of science (8).

In summary, one can infer that (a) there are distinct ways that teachers and students in the new sciences should behave; (b) these behaviors can be identified and reliably observed and rated; (c) the interactions between teacher and student in science can be more or less consistent with the nature of science and the goals and objectives of the curriculums which have been developed; and (d) if teachers utilize certain of the behaviors described they are likely to elicit different responses from their students than if they do not use these behaviors. For example, if the science teacher asks questions which require yes-no answers, he is likely to get those answers. However, the student's learning no doubt will be very different from that he gains when the teacher asks for data interpretation or for hypotheses and generalizations. The latter questions require students to do and say things that are more consistent with the goals of modern science. Hence, it is probable that the resultant learning in this case will be more appropriate than the learning derived from yes-no questions. This relationship has yet to be completely investigated, however.

OUTCOMES OF INSTRUCTION

Factual and Conceptual Outcomes

There is a mass of research which has been directed at comparing the effects of new curriculums with so-called traditional curriculums. For the most part the research is inconclusive. However, it does appear that one could say that the new and traditional instructional materials contribute equally well to student growth as measured on fact- or concept-oriented tests.

Understanding of Science and Critical Thinking Outcomes

New curriculums, if they have an advantage across the board, could be said to positively influence such things as critical thinking ability and understanding of the nature of science and scientific

inquiry. (The effects of the latter curriculums are influenced profoundly by how they are taught and what outcomes are emphasized.) Outcomes in these areas are generally thought to be among the most important for science instruction. In practical usage, the understanding of science refers to a wide range of things, including being able to describe the influence of science on society, to being able to use certain methods and procedures in the laboratory to solve problems. Studies which attempt to measure achievement of these outcomes suggest that if a teacher uses a problem-solving method either in lecture or laboratory he is likely to highlight problem-solving skills and strategies and thereby positively influence the acquisition of these skills by students. The problem-solving approach frequently is defined as emphasizing stepwise analysis of discrepant events, teacher presentation of examples, student attempts at the development of generalizations, and inductive and open-ended strategies. It appears, however, that the information-giving approach produces an equivalent amount of *content* learning as does the problem-solving approach.

Studies exploring BSCS biology and various methods of teaching it revealed that those classes using BSCS materials and employing practices advocated by BSCS had significantly greater gains in pupil understanding of the nature of science, as measured by the Processes of Science Test (POST), than two other groups (24).

One study of BSCS materials concluded that laboratory experience emphasizing the development of particular skills was effective in developing skill with laboratory materials and procedures. Measures of achievement in the areas of content and critical thinking were not significantly different between the laboratory and nonlaboratory demonstration groups (56). In another study the same researcher varied the emphasis of the teacher in the classroom by varying the number of references used with the same laboratory approach. He found that a multireference laboratory approach was more effective in developing critical thinking in students than a single reference (textbook) laboratory approach. Similarly, a multireference approach produced greater understanding of science. Both approaches do equally well in developing a mastery of the major concepts and facts of biology (55).

A study comparing manipulative versus nonmanipulative approaches to Introductory Physical Science (IPS) found no significant differences in terms of student progress in critical thinking skills, understanding of science, and conceptual knowledge in IPS. The manipulative method, which provided greater experience with laboratory materials and methods, did produce greater acquisition of selected laboratory skills (40).

A study in chemistry attempted to compare inductive-deductive versus deductive-descriptive approaches to laboratory instruction. It is difficult to visualize all of the ramifications of the treatments, but one would guess that the inductive approach was less directive, observation-inference oriented and the deductive approach more directive, with the teacher presenting generalizations and the laboratory used to confirm these. The results indicated the superiority of the inductive approach in terms of knowledge of and ability to use the scientific method. This was accompanied by a "positive" scientific attitude and an increase in the ability to identify proper laboratory techniques (10).

Two studies relating to teacher and student questions in class deserve some consideration here, since most of the new curriculums emphasize certain types of questions as at least part of the inquiry process. The first study attempted to explore the types of questions teachers ask in science classes and laboratories and the resulting student understandings. The findings indicated that the students of teachers who ask more critical thinking questions tend to understand science better. Although fewer questions are asked when critical thinking is the objective, as opposed to rhetorical or factual information, critical thinking questions make greater demands on the student's classifying and associative powers. One could characterize critical thinking questions as those requiring students to go beyond yes-no or fact answers and to analyze, synthesize, or evaluate ideas and conditions (23).

The second study, on the other hand, investigated the relationship between teacher behavior and thought-provoking questions by students. The results were that teachers who tended to be more indirect appeared to have more students who asked thought-provoking (or higher level) questions (21). This seems intuitively reasonable, because a less direct teacher

probably provides more of an opportunity for students to participate, and at the same time probably has other behavior correlates which would contribute to this outcome.

The following conclusions may be derived from the foregoing discussion of research. If a teacher arranges instructional conditions and formulates his objectives in terms both of knowledge and process and makes these objectives known to the students—providing the teacher's behavior falls within the acceptable range of the behavior models described earlier—he probably will produce positive student change. If the teacher emphasizes the nature of science and the use of the processes of science and critical thinking in class and laboratory, students are likely to acquire the skills emphasized. Little or no emphasis on such instructional objectives is likely to detract from learning of the skills; rather, less useful skills will be learned. For both critical thinking and understanding the nature of science an instructional procedure which emphasizes laboratory activity appears to be superior to non-laboratory experiences. Of course, the laboratory experience must be designed carefully to elicit particular responses and must be taught in a way which corresponds with the objectives of the science curriculum or the results are likely to be negative. Finally, teacher questioning appears to be an important component of science teaching. Students who are challenged to respond to higher level questions, requiring inference, theory development, and data analysis, are likely to learn how to think critically. Accordingly, if a teacher uses higher level questions in a more or less open atmosphere, students are likely to engage in critical thinking and, in turn, ask similar questions.

Affective Outcomes

The acquisition of facts, concepts, and particular inquiry skills represents what are called cognitive learning outcomes, or the learning of thinking skills. Another important area is affective learning components, or positive ways to feel or react to the scientific enterprise and procedures (35).

A 1969 study proposed that scientific process activities required a frame of reference in the form of an attitude which must be acquired early in science instruction. An analysis of the literature in the philosophy of science led to the identification of a number

of attitudinal characteristics which are thought to represent a "positive generalized attitude toward science." Some of these characteristics follow:

1. A predisposition to discern the degree in which one person or thing differs from another; a tendency to emphasize differences.
2. A tendency to challenge authority; to test traditional beliefs and outcomes with actual observation and experience.
3. A readiness to change as changing conditions require; a multiple and flexible approach to people and things.
4. An ability to differentiate between controlled and reliable observation as opposed to casual observation.
5. A basic notion that reality is to be regarded as a process implying continuous change; no two things are exactly alike; no one thing stays the same.
6. Structure in the form of relations and equations will be stressed over function; structure, the nature of the phenomenon, the broad unifying principle, is stressed rather than application or function.
7. Greater concern for research rather than findings; greater emphasis on the inquiring, the questioning, rather than the final answers obtained; the form of the question is considered more important than the answer observed.
8. An emphasis on probability-type explanations rather than absolute solutions (52).

One outcome of science instruction is to change student behavior; the other is hopefully to influence attitudes and feelings positively. It is probable that there is an extremely close positive connection between the two.

A number of studies using various curriculum materials and methods have attempted to produce attitude change or acquisition of certain attitudes. One researcher, working on the verbal behavior of student teachers in BSCS biology, found that student achievement and attitude toward science were significantly better in classes where the teacher was "indirect" (29). The various studies also confirmed that attitude could be influenced by instruction. There are also a number of studies

which found that attitudes could be influenced by inductive methods of teaching, laboratory experiences, and problem-solving experiences.

The critical factor for teachers to bear in mind is that they must plan as carefully for attitude change as they would for behavior change. Hence, it is incumbent upon the science teacher to identify those attitudes which he wishes to influence and then to design and test various methods to influence them. The achievement of an affective objective may go further to influence the permanency of desired behavior than the focus on initial behavior change alone.

Creativity Outcomes

A group of researchers in the area of creativity and creative thinking derived some interesting generalizations regarding both the nature of creativity and possible ways of influencing it. The following definition of creativity is prominent in current literature, but by no means is the subject of total agreement: "The creative child prefers to explore the unknown, rather than to conserve the already known. He prefers explaining facts in new ways rather than continuing to rely on traditional well-established explanations; he indulges in adventuresome thinking and raises questions, rather than being content with things as they are" (12). It is generally agreed that the creative child is "intellectually curious and exploratory, taking an active part in manipulating and reconstructing his environment." Researchers present a number of ways to foster creativity, based on the assumption that creativity is learned. They find that an environment that is permissive and stimulating appears to play an important role in establishing the conditions for creative output. They also stress that an effort should be made to acquaint the student with some characteristics of creative thinking and action. Without this knowledge it is felt that students have little notion of the nature of creativity, hence little understanding of how to perform creatively. The following are part of a repertoire of creative thinking skills: (a) the ability to recognize gaps in existing information; (b) a facility for formulating relevant questions; (c) a sensitivity to the demands of the task so that the student can be an adequate judge of the suitability of proposed ideas; and (d) a sense of disciplined abandonment. The

program that was offered for fostering these behaviors was a general problem-solving program which included the use of hypothetical problems (12).

One is struck by how closely the recommendations of the group of researchers on creativity parallel procedures which are thought fundamental to science instruction: Provide the student with instruction as to the characteristics of the creative act. Provide an open environment in which the child can operate. Help the student analyze what he is doing, and perhaps evaluate it. Provide ample opportunity to be confronted with and to solve problems. The foregoing suggestions are very similar to teaching inductively, providing laboratory experiences with scientific problems, evaluating the products of the laboratory, etc. Accordingly, it might be argued that at least some of the outcomes of science instruction are directed at producing a creative approach to one's environment!

INSTRUCTIONAL METHODS AND MATERIALS

One of the major emphases of present instructional methods and materials is to individualize instruction. There are a number of ways to individualize instruction for science students. A way which is receiving considerable attention in both psychology and science education is the consideration of student aptitude and the application of appropriate treatment or modes of instruction and materials. The aptitude-treatment theory suggests that the optimal instructional sequence might be arrived at if teachers had specific information about the cognitive skills of the learner—for instance, whether the learner was highly inductive, deductive, or verbally fluent. The mode of instruction is chosen then to correspond with these aptitudes (13). Students high in inductive skills might be taught a certain concept by using an inductive program, while those high in deductive skills might require a deductive program. In practice this is rarely done. The closest we come to this approach is to group students within a class, or to place them in classes on the basis of mathematics achievement or verbal ability. On the other hand, many of the new science curriculums, particularly BSCS and Project Physics (46), have produced a wide range of instructional materials, such as study guides and text-

books, laboratory guides, readers, programed instruction materials, transparencies, film loops, home demonstrations, laboratory blocks, and the like. The intent here is to provide a range of instructional methods and materials the better to "fit" the different levels of interest, rates of learning, and aptitudes of students. Finally, varying the mode of instruction from large group to laboratory, small group, and individual work provides an opportunity for both teacher and student abilities and interests to be exploited in the instructional situation. Following is a review of some of the findings and generalizations regarding specific instructional methods and materials.

Flexible Scheduling and Team Teaching

A flexible schedule could be defined as a system of arranging the curriculum and school schedule to provide both blocks of time and space for large-group instruction, small-group instruction, independent instruction, laboratory instruction, and the incorporation of a multimedia method of instruction. Team teaching can be described as a cooperative effort among teachers in a school which brings together resources of communication, talent, and planning beyond that of the single teacher in the classroom.

A study conducted in 1963 attempted to determine if teachers of BSCS biology felt that they could teach the new curriculum more efficiently and effectively within a flexible schedule. Responses from the California BSCS tryout teachers indicated that they, indeed, felt it would be an important aid to effective instruction, particularly in the laboratory (27). Other studies confirm that both teachers and students are receptive to team teaching and modifications of the existing format of instruction. However, those studies which have attempted to measure the effects of one or both of these variations on student achievement have found that neither one produced greater learning than the conventional schedule and teaching situation.

If team teaching is no more effective than the regular format in promoting academic achievement, investigators might turn their attention to attempts to determine whether team teaching is superior in promoting outcomes other than academic achievement. One researcher pointed out that it seems to have a positive effect

on teacher morale (39). In a similar way, it may affect affective components of student learning, such as interest in the subject, inclination toward autonomy in learning, the acquisition of skills which contribute to learning to learn, and the like. Consequently, even though very extensive studies suggest that team teaching is not more effective than conventional instruction (34), it appears too early to discount this mode of instruction until a wider range of possible outcomes of team teaching and modified scheduling has been explored.

Film Instruction

Films may be used as a part of an instructional system or as the entire system. Experience has shown that science students in nonfilm classes either achieved more or equally as much as those in film classes. Some of the explanations for this are that films used as the only means of instruction tend to be boring, non-motivating, and lacking in the characteristics which are commonly thought to encourage learning. Students in nonfilm classes are able to ask questions, answer questions, receive reinforcement for their correct responses, and practice certain types of responses. Each of these experiences has been found to be necessary, but perhaps not sufficient for learning. Since students in classes where films constitute the entire program do not have an opportunity to do any of the above, it is not surprising that their learning does not match or exceed nonfilm groups. A general survey of the literature in this area indicates that film courses alone are not a good overall instructional method (53). However, the judicious use of films in combination with other instruction is a promising instructional procedure. One investigator has pointed out that in order to derive the most benefit from the use of films as aids to instruction the teacher should preview the film, provide an introduction or set prior to showing the film, conduct follow-up discussion of the major points in the film, and, if possible, intersperse question-and-answer sessions between sections of the film (31). In general, these suggestions appear to apply equally well to the use of television in the schools.

Visual Aids

Films, transparencies, audio tapes, slides, film loops, and pictures can all be used as effective aids to instruction, either collectively or with other teaching methods, to achieve certain cognitive and affective objectives in science. Studies have shown, for instance, that pictograms, shaded drawings, and single concept film loops all appear to be effective aids when used as part of an instructional sequence. When film loops are used, it appears that a questioning-inductive approach is more useful than an information dissemination approach. Similarly, hypothesis generation appears to be facilitated when film loops are accompanied by questions. It is probable that one could generalize from film loops to transparencies and slides.

When using any of these aids it seems important that (a) the teacher clearly define what the performance outcomes of the instructional system and its parts are to be; (b) the teacher identify and plan a combination of both teaching strategies and aids to achieve specific objectives; and (c) the teacher observe student performance in both the cognitive and affective areas during instruction to gather feedback relative to the effects of the sequence of materials and the type of aid on different students. An integrated approach combining teacher presentation with audiovisual material will undoubtedly produce desired behavior change in students.

Programed Instruction and Computer-Assisted Instruction

Considerable interest has been expressed in the areas of programed instruction and computer-assisted instruction (CAI) by science curriculum developers because these developments may provide a way to individualize instruction, an efficient way to present certain kinds of content, and an opportunity to control or at least influence certain aspects of the learning environment. Both of these instructional programs permit the student to move at his own rate toward a goal, to move in small steps of gradually increasing difficulty, to make active responses to the items in the program, and to find out whether the responses he made are correct or incorrect. Programs may be of two types: linear or

branched. In the linear program the learner receives information, makes a response, and gets feedback. This sequence is repeated throughout the program. In a branching program a segment of content is presented, a question asked, and the learner responds. If his response is correct, the learner moves on. If incorrect, he is told it is incorrect and is directed to an explanation. Then he returns to try the same task again. Linear or branching programs are "generally equally effective" (30). If material is primarily descriptive information that is new to the student, a linear program appears to be best. If the material to be learned is more complex and involves reasoning on the part of the student, then a branching type appears better.

Studies with various curriculum materials have shown that linear programs were of value in tightly knit subject matter areas in chemistry connected by logic or arbitrary rules (7). Students were generally favorable to such programs (43). Programed materials were effective in teaching a variety of topics, such as chemical bonding, geometry of molecules, photon theory of light, and population genetics.

In conclusion, programed instruction and CAI appear to be valuable aids to instruction for specific types of content, interspersed with other instructional methods, and with certain kinds of students. As in the case of other media, programed instruction or CAI as the only mode of instruction would probably induce boredom and lack of motivation in addition to inefficient learning. However, when they are used as an integral part of a larger instructional system they appear to be highly effective in producing learning of certain types of tasks.

Audiotutorial or Multimedia Systems

The audiotutorial approach to teaching (42) is not a unique instructional innovation in and of itself. Research cited earlier suggests that the sensible approach to instruction is the employment of various media in varied instructional settings to permit the learner to move at his own pace toward specific instructional objectives. Multimedia systems provide this opportunity, but are subject to the same questions that one might ask of other modes of instruction or teaching aids: What evidence is there of the individual effects of components of the system, on what behav-

iors, under what conditions, for what kinds of students, etc.? The multimedia system, taken as a system, is undoubtedly effective in achieving certain outcomes because of the sheer power of some of the subsystems. But at this time research is lacking on the relative contribution of individual subsystems to overall multimedia systems.

Much of the research reported on the use of an entire multimedia system is encouraging. For instance, researchers with the Project Physics course point out that such a system "enables the teacher to spend more time guiding individual students and small groups since the teacher spends less time teaching and explaining to the class as a whole" (51). With multimedia systems the potential for using independent study increases. Teachers using a multimedia approach to the Project Physics course felt that their students showed more interest in the subject, asked more questions, and demonstrated deeper understanding in small- and large-group discussions. The students responded well to the approach as indicated by gain scores in achievement over a trial unit. In addition, the teachers felt that they got to know the students better as their role shifted from purveyor of information to tutor-guide. Promising results of the type described have also been noted in other physics programs, earth science instruction, and biology.

In conclusion, it appears that the multimedia approach to instruction, which integrates many materials, audiovisual aids, contexts for student learning, and methods of teacher behavior, is an effective instructional system and a step toward the ideal of an individualized program of instruction for students in science. One cautionary note should perhaps be sounded here. Although single medium and multimedia appear to be effective instructional methods, the science teacher should be aware of the inquiry goals of science and not narrow the potential for student inquiry through the use of restricting media. The media selected, as well as the teaching style, should correspond with appropriate objectives in science.

Organization of Content

A well-known researcher proposed that conceptual knowledge and skills in a discipline form a hierarchy (14). Lower levels of the

hierarchy must be mastered before higher level skills and knowledge can be attained. This suggests that science content should be organized in a particular sequence or structure. Inquiry skills in science can be translated to behaviors or intellectual skills and organized hierarchically for cumulative learning. Facts or verbalizable knowledge do not lend themselves to the same cumulative learning theory, but they can be memorized and retrieved without undo effort.

Research in science in this area has been sparse. One study in science found that "subjects who received highly structured program lessons acquire significantly more science knowledge than subjects who received lessons low in structure" (2). Similarly, at another time this researcher expressed the opinion that "decreasing levels of structure in programed lessons induce a related decrease in response acquisition" (1).

In a Plant Morphology course on the college level it was demonstrated that it is indeed possible to operationalize process skills in science, to arrange these hierarchically, and to individualize science instruction by differentiating between the entering level skills of students on the basis of this hierarchy (19).

In conclusion, it appears reasonable to assume that the sequence and structure in which science is presented to students will affect how well students learn the material. Science concepts and inquiry skills may be organized in a multitude of ways for presentation and may be presented in a wide variety of sequences for any of the sciences. It is necessary for the individual teacher to test alternative sequences of concepts and processes and also alternative methods of presentation in order to arrive at those which work well with a particular group of students under certain conditions.

Concept Formation

The psychologist defines a concept as "learning to make a common response to a set of stimuli; that is to say, a group of stimuli is assigned to a single response category" (17). In science, observing, classifying, collecting data, and arranging data are among the critical laboratory processes which contribute to concept formation. It is probable that students who know what a concept is, know what the characteristics of formation are, and are aware of

the role of laboratory experiences in formation will be able to go about encoding and decoding information necessary for concept formation. Hence, teaching students how to form concepts appears to be as relevant as teaching actual concepts.

Whether through experience in the laboratory or through verbal instruction, concept formation is a searching process. The student must explore a mass of unordered facts, observations, or events for similarities and differences and look for those characteristics which permit organization and integration. The teacher must provide opportunities for this to take place by arranging conditions so that students will have the necessary experiences in the laboratory and the classroom. Concept learning involves decision-making activities, such as (a) reducing the differences; (b) finding organizational properties for the information; and (c) validating the conceptual organization given to data (20). Consequently, concept teaching in science must not be comprised solely of teacher exposition. Rather, a combination of laboratory inquiry and in-depth classroom inquiry is necessary. Even though the instructional situation is "planned," it must be open and fluid.

When teaching concepts in science, the teacher should attempt to employ a number of different approaches to the concept and provide examples and experiences which are not context-bound. For example, diffusion and osmosis could be considered in a variety of living systems. But diffusion also can be exemplified in several other contexts, such as the diffusion of gases. If the context within which a concept is acquired is not varied, it is likely that students will consider the concept bound by the parameters of the single context in which it was learned, as might be the case if diffusion was presented solely as the movement of a gas in a room. If other contexts are not provided, this conception becomes the only concept formed. Carefully selected experiments, demonstrations, readings, illustrations, and examples all contribute to releasing a concept from one context. For this reason, multimedia systems can play a great role during concept formation. In the laboratory, students should be encouraged to try other experiments related to the one conducted and to use their reading as a guide to the processing of data. Frequently, audiovisual aids, such as single topic films, transparencies, and slides, provide an opportunity to shape responses and to vary the amount and kind of data. The pacing during concept formation is

critical, since rapid pacing may result in premature decisions regarding the nature of the concept or the extent to which the concept can be generalized.

In the main, simple concepts have been found to be formed more efficiently through the presentation of positive instances. Negative examples have been found to be less efficient, unless the student has been specifically prepared to use this type of information. Similarly, concept formation seems to be expedited if the teacher clearly defines what is to be the student's role and what he is expected to be able to do or say at the end of the session. The difficulty of concept formation is increased if the number of relevant characteristics of an object or event is increased. As the information load required to form a concept increases, the difficulty of formation increases. Hence, it is imperative that teachers at least modulate the amount, type, and context of information at any one time.

Concepts and conceptual schemes are the backbone of any scientific discipline. They provide a means for educators and scientists to organize the growing knowledge in science into more manageable parts. Once a concept is mastered, it permits the learner to acquire and incorporate new knowledge into the established conceptual structure. Laboratory activities contribute to a growing structure of knowledge comprised of concepts. By their very nature, concepts facilitate an economy of thought and release the learner from a dependence upon the remembering of discrete percepts. For these reasons, it is imperative that instruction in science place a heavy emphasis on concept formation.

SCIENTIFIC SKILL DEVELOPMENT

Among the skills students should acquire as a result of science instruction are inquiry or process skills. A method frequently advocated for acquiring these skills is variously referred to as inquiry, discovery, or problem-solving teaching strategies. On the one hand, we might think of the scientific processes as being part of the content of science. But, on the other hand, they are also proposed as methods to facilitate learning of this content. In keeping with earlier discussions, these skills will be considered here as objectives of science teaching and tasks for science stu-

dents to learn, rather than as teaching or learning styles. This position is in agreement with the argument "that it is somewhat unrealistic to expect that subject matter content (in science) can be acquired incidentally as a by-product of problem solving or discovery experience ... rather, the development of problem solving ability is a legitimate and significant educational objective in its own right. The principal function of the laboratory is not to transmit subject-matter content or to demonstrate principles of science on an audiovisual basis, but to teach the scientific method" (4).

Given, then, that inquiry is an objective of instruction, how do we foster it? A body of psychological research on problem solving has some bearing on this (18). The research indicates that during thinking activities, such as problem solving or inquiry, the learner is not tied to a particular fixed set of stimuli, but is called upon to rearrange or reorganize stimuli to correspond with a given situation. The learner then must be taught to look upon these experiences as an opportunity to utilize or apply concepts learned in class and procedures previously learned in laboratory. A critical factor in attacking a problem of any type is defining the problem. Teachers can be helpful here by providing examples of similar problems, by helping students collect their thoughts, or by a limited amount of prompting. Since thinking and problem solving take place through the use of rules or principles which are built up from previously learned concepts, it is thought that students can be taught to function independently, recalling their inquiry strategies. It is important for the science teacher to be aware during laboratory sessions that there are many types of inquiry or problem-solving products; consequently, there are many types of inquiry conditions and approaches. For instance, a student is likely to use a more structured approach to establish a "limiting factor" in a biological system, but a very much more open or fluid approach to the analysis and evaluation of inquiry or problem-solving methods. Hence, the door must be left open to a wide range of student behavior.

An outcome of problem solving is the development of models for future problem-solving strategies when the problems are similar or have similar components. For instance, the learner solves a problem by applying a combination of rules which form higher order principles. Eventually these principles may be generalized at

a number of levels to a variety of similar problems. In science courses, then, a major focus should be on the education of students in the prerequisite concepts and conceptual sequences, along with major generalizations the application of which will be useful when the student confronts new laboratory problems.

THE EVALUATION OF LEARNING

This entire booklet has been devoted to the proposition that it is possible to describe in terms of specific behavior teaching and learning in science. If this is the case, more efficient evaluation should follow. More efficient evaluation suggests the following types of activities.

For the evaluation of both teacher and student performance, start by specifying expected outcomes in terms of observable performance. Establish through objectives minimum levels of performance. Try to specify expectations for both the classroom and the laboratory, with an emphasis on conceptual and skill development which corresponds with the nature of science. Design instructional systems for classroom and laboratory which increase the probability of achieving anticipated outcomes. And, finally, use the feedback from instruction to modify future instruction. Constantly guard against becoming so structured and specific that important inquiry objectives in science are neglected or negated.

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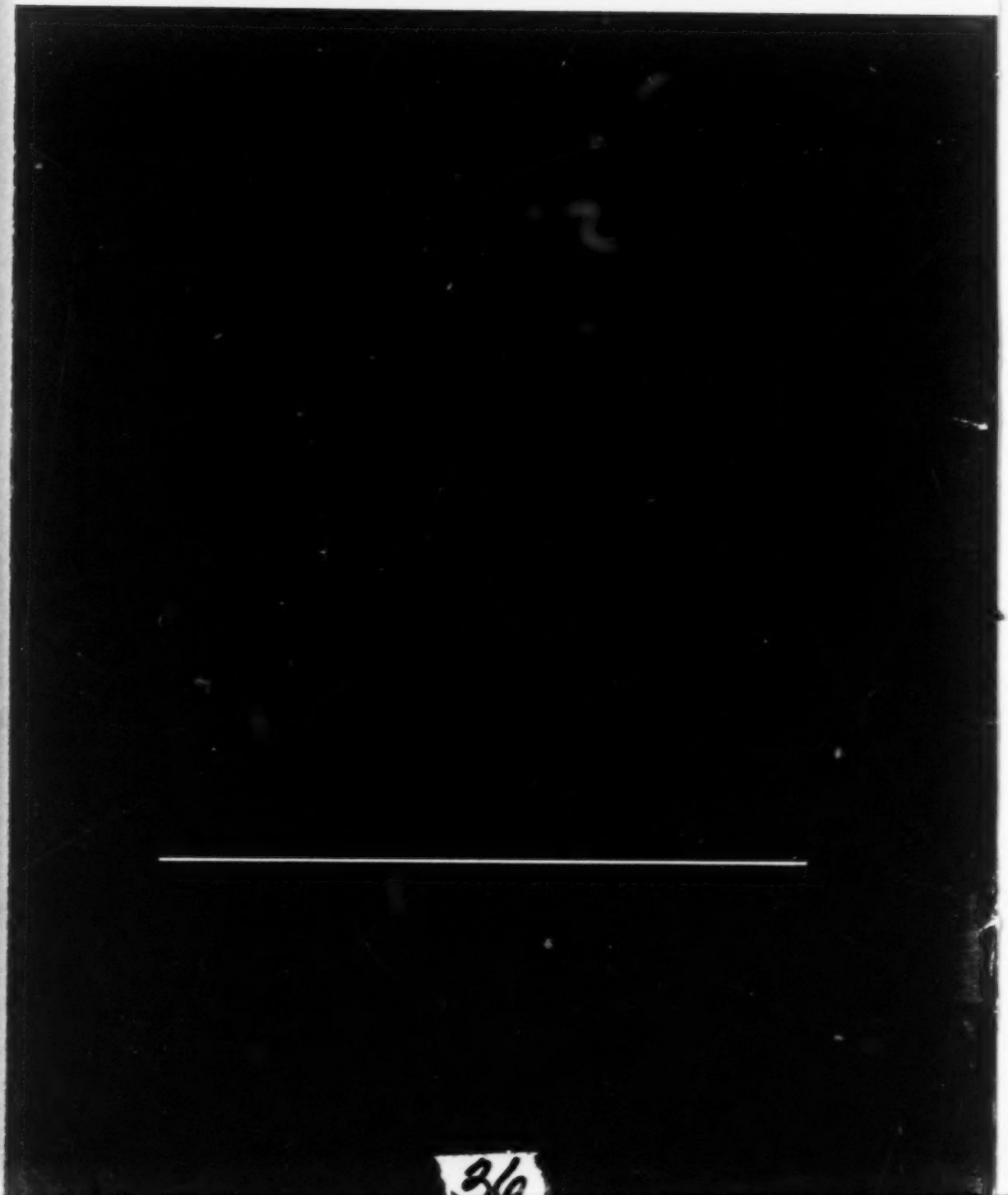

86